# Development and Clinical Application of Instruments to Measure Orofacial Structures

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## 1. Introduction

The human body consists of a series of systems, which work in an integrated way for perfect functioning. One of these systems, the muscular system, consists of a set of muscles that are able to contract and relax, resulting in the generation of diverse and varied movements that allow the person to walk, eat and talk, and perform many other actions.

The muscle groups that integrate the human body have different characteristics. There are long muscles, which are powerful but not so precise in their movements, while another set of muscles is described by their small size and high accuracy in generated movements.

The muscles which compose the orofacial system are characterized by their small sizes and the ability to generate highly precise and differentiated movements that includes a series of rapid shape changes. This is made possible due to the large amount of innervations and the complex organization of the muscle fibers. These muscles play an essential role in mastication, swallowing, speech, breathing and suction, functions that require fast and complex movements. They also contribute to the orientation of facial bone growth and maintenance of teeth position.

Like all systems that constitute the body, many diseases can cause changes in the structures that compose the muscular system. Changes, such as muscle weakening, that interfere in tongue and lips movements can hamper activities related to various physiological processes. When any disorder or other conditions causes an improper functioning of orofacial muscles, it is necessary to rehabilitate the impaired muscle group. This muscular rehabilitation work, named myotherapy, includes orientations and rehabilitative exercises and it shall be carefully planned in order to achieve fast and effective results. However, to organize a work plan it is essential to perform a well-structured assessment of muscular condition.

Currently, the evaluation by speech-language pathologists of these muscles is routinely made in a qualitative way. One of the current evaluation techniques consists of asking the patient to perform a contraction against an imposed obstacle, such as a gloved finger. Based on experience, the speech-language pathologist classifies the force as normal or not.

For several years, an effective method has been sought to quantify the force or pressure that orofacial structures are able to exert. This method would allow comparing the values with the parameters obtained in the qualitative evaluation and to measure performance during the main functions and exercises. A quantitative evaluation can improve diagnosis, especially in cases of slight changes in force and is more sensitive in detecting the small differences in strength observed with the progression of the disease or therapy.

The field of Biomechanical Engineering combines engineering with biology and physiology, using principles of mechanics to design, model, develop and analyze equipment and systems. In Brazil there are Biomechanics research groups in different regions of the country, although mostly concentrated in Southeast of the country. In this region is the Biomechanics Engineering Group from the Universidade Federal de Minas Gerais, an interdisciplinary group, was created in 1998, and includes researchers from the fields of engineering and health care. The purpose of the group is to study the mechanical behavior of tissues, organs and biomaterials under the action of external loads and other types of actions using computational and experimental techniques. In 2002, a professor and a few Speech Language Pathology undergraduate students joined the group with a project that aimed to develop instruments for quantifying the forces of orofacial structures in order to help in orofacial myology assessment. The first instrument created was FORLING, to measure tongue force. After that, the group started to grow, with more undergraduate and graduate students, and started a new project: the development of an instrument to measure lips force, FORLAB. Both of them were intended to be used in the stages of diagnosis, prognosis and therapeutic follow-up.

This chapter focuses on describing the development of devices and quantitative techniques created by the Group, to quantify forces and improve the assessment of orofacial muscles. It also includes an analysis of the obtained values of tongue and lip forces and a discussion on the consequences of the obtained data on clinical practice.

## 2. Tongue

### 2.1 Anatomy and physiology of the tongue

The tongue is a highly specialized organ of the body and a focal point for many professionals from several fields of knowledge. It actively participates in functions such as sucking, mastication, swallowing and speech, which are fundamental in maintaining the quality of life. It is a mobile structure that can take many shapes and positions, in extremely fast sequences, due to its high innervations and complex organization of muscle fibers (Zemlin 1997).

It is characterized as being essentially a muscular organ, which occupies the functional space of the oral cavity. It is formed by striated muscle tissue and covered by a flat mucosa in the lower part and is irregular on the top due to the large number of papillae (Aprile et al. 1975).

The tongue can be divided into body and root, or, based on its relationship with the palate, into apex and body. The body can be subdivided into the front and back part. The apex of the tongue is the part closest to the anterior teeth; the region just below the hard palate is the front and the region located below the soft palate is the posterior (Zemlin 1997).

The dorsum of the tongue is divided by the longitudinal sulcus, which is continuous from the back to an orifice called the foramen cecum. From the foramen cecum, a shallow V-shaped sulcus, called terminal sulcus, has its anterior and laterally path toward the edges of the tongue. This is the anatomical reference point that separates two anatomically and functionally distinct regions, the anterior two thirds and the posterior third of the tongue. In the anterior two thirds, the dorsum has a rough surface and contains the taste papillae, while the posterior third of the tongue looks smoother and contains numerous mucous glands and lymph vessels that form the lingual tonsil (Zemlin 1997).

The lingual septum divides the tongue into halves and its muscles are considered in pairs. The muscles of the tongue are classified as extrinsic and intrinsic. The extrinsic muscles (Figure 1) originate in adjacent structures and are inserted into the tongue, being responsible for movement in different directions. They are: genioglossus, styloglossus, palatoglossus and hyoglossus. The genioglossus is the largest of the extrinsic muscles and is fan-shaped. The contraction of the posterior fibers moves the tongue forward, protruding the apex, while the contraction of the anterior fibers causes tongue retraction and the contraction of the whole muscle moves the tongue down. The styloglossus, during its contraction, moves the tongue upward and backward, and along with the superior longitudinal muscle, directs the sides of the tongue upward to make the dorsum concave. The function of the muscle palatoglossus is to lower the soft palate or to raise the back of the tongue grooving the dorsum. The hyoglossus retracts and depresses the tongue (Zemlin 1997).
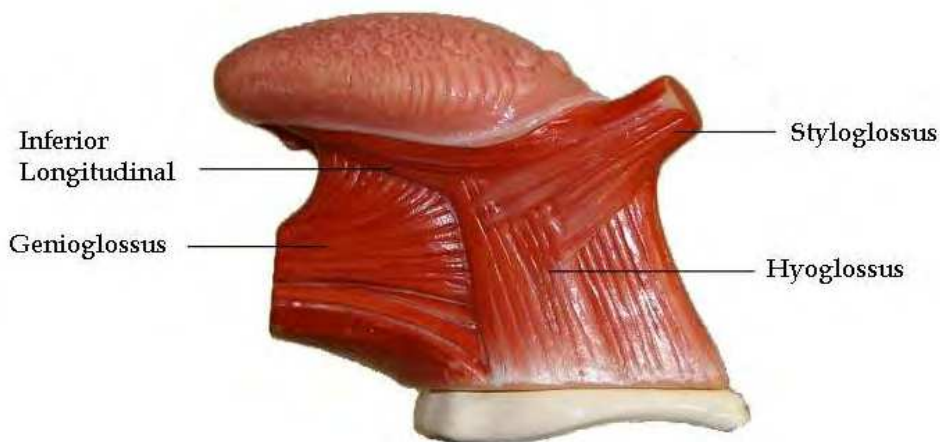


Fig. 1. Extrinsic tongue muscles and the inferior longitudinal

The intrinsic muscles (Figure 2) are contained in the tongue itself and are responsible for changing the shape of the organ. They are: superior longitudinal, inferior longitudinal, transverse and vertical. The superior longitudinal muscle shortens the tongue and turns its apex upward. The oblique fibers help turn the side margins up, leaving the back concave. The inferior longitudinal shortens the tongue, pushes the apex downward and leaves the dorsum convex. The vertical muscle flattens and extends the tongue, while the transverse muscle narrows and lengthens the body (Zemlin 1997).
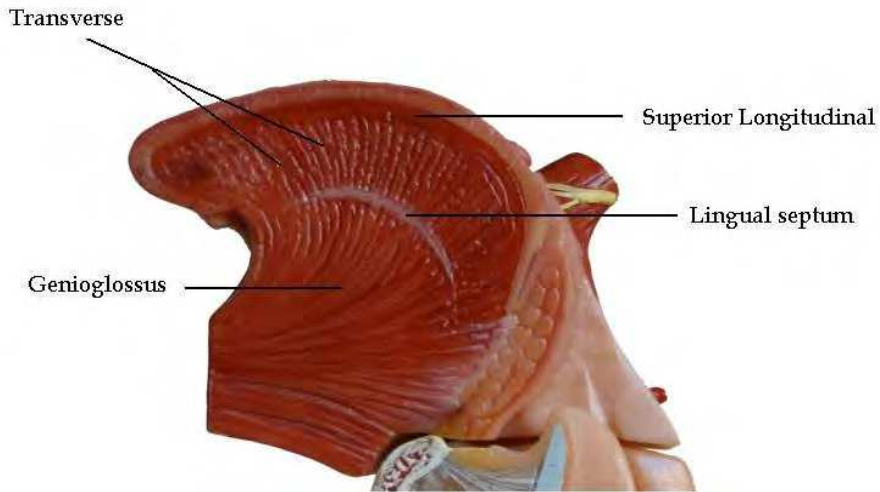
Fig. 2. Intrinsic tongue muscles and genioglossus

Although the genioglossus muscle is considered the most powerful extrinsic lingual muscle (Zemlin 1997), in cases of a protruding tongue against a resistance, genioglossus activation plays an important role, but not a primary one. It actually provides a stable platform against which the intrinsic muscles of the tongue in the anterior part can develop strength (Pittman and Bailey 2009).

Both intrinsic and extrinsic tongue muscles are innervated by the hypoglossal nerve (cranial nerve XII) (Zemlin 1997); Douglas 2002), except the palatoglossus muscle, which is innervated by the glossopharyngeal (the ninth pair of cranial nerves) (Douglas 2002). As for sensitivity, the tongue presents refined taste activity, which results from the action of some nerves, such as the trigeminal nerve, which provides the overall sensitivity of the anterior two-thirds, the glossopharyngeal nerve, responsible for the overall sensitivity of the posterior third and the facial nerve, which is responsible for taste in the anterior two-thirds (Dangelo and Fattini 1998).

### 2.2 Instruments described in the literature to measure tongue force/pressure

Kydd (1956) quantified tongue force of an edentulous 30-year-old man using a device composed of a denture base made of methyl methacrylate, whose vertical dimensions were maintained between the bases by four vertical rods embedded in the lower denture base. There were three blocks of methyl methacrylate between the rods, positioned to replace the lingual surface of the lower incisor area and second premolar-first molar areas. Electric resistance strain gauges were attached to these blocks. The pressure exerted by the tongue on the block produced a deformation on the gauge, modifying its resistance. An alternating current amplifier and a multichannel pen recorder were used to provide dynamic as well as static recordings. It was found that 23.13 N was the maximum force exerted anteriorly, and 11.56 N and 10.23 N laterally in the right and left lower first molar-second premolar areas, respectively.

Posen (1972) measured maximum tongue force in subjects with and without problems in occlusion. The instrument was made of a gauge to give a reading of up to 50 N when pushing a spring that was attached to the gauge. At the other end of the spring, there was a concave piece where the tongue exerted force. Subjects with normal occlusion exerted forces between 6 N and 25 N.

Dworkin (1980) measured tongue strength using one semiconductor strain gauge welded to a tubular stem for easy insertion into the mouth and a single channel pen-writing portable recording system. The force transducer could be positioned anteriorly between the upper and lower incisor teeth, or laterally, between the canine and first bicuspid teeth, and the subject was requested to bite down on the stem and apply tongue pressure against the transducer with the tongue tip. The maximum force exerted by normal subjects was 20 N anteriorly and 16 N laterally.

Scardella et al. (1993) measured tongue force using a force transducer that translated direct compression forces generated by the tongue into an active arm outside the mouth connected to a strain gauge with a linear response for forces between 50 gf and 100 gf, which was incorporated into a two-arm active bridge circuit. Five normal male subjects (ages 21 to 36) were evaluated. The maximum force ranged between 9.50 N and 16.33 N, with an average maximum force of 12.67 ± 1.25 N.

Mortimore et al. (1999) used a transducer consisting of a machined nylon hand grip and a mouthpiece. The mouthpiece consisted of a 1-cm diameter nylon plate behind which was positioned a 6 kgf button load cell, which responded to tension and compression. Behind the plate, the mouthpiece consisted of a groove approximately 2-mm deep and 2-mm wide. Subjects were asked to rest their upper and lower incisor teeth against the groove in order for the transducer to reach steady state. The force was then exerted on the plate by the subject's tongue. The transducer was connected to a linear visual scale displaying the force in Newton (N) or as a percentage of the subject's maximum force (measured during a previous trial). Eighty-six females and eighty-one males aged between 42 and 62 years were evaluated. An average maximum force of 26 ± 8 N for men and 20 ± 7 N for women was recorded.

Bu Sha et al. (2000) measured tongue force using a custom-designed lingual force transducer housed in a piece of polyvinyl chloride tube. The tube was bisected lengthwise and a latex balloon catheter was mounted between the two halves of the tube and secured in place with dental impression material. The balloon was positioned so that when it was inflated with 4 mL of saline, it protruded 1.0 cm beyond the end of the tube. A 2-mm thick rubber sheath covered the end of the tube, providing the subject a soft, stable surface to bite when producing protrusion efforts. The sheath was marked at 0.5 cm intervals from the balloon end of the tube over a length of 4.0 cm. The balloon catheter was connected to a pressure transducer and the output was amplified, recorded and reconverted into force. The subject held the transducer in the mouth and bit down on the tube. With the tip of the tongue on the balloon, increasing or decreasing the depth of the transducer in the oral cavity increased or decreased the length of the tongue muscle fibers. The maximum measured force was 28.0 ± 2.0 N. Most subjects had a maximum force at a transducer position of 2.5 cm.

A study was conducted with a device developed by the Biomechanical Engineering Group of UFMG named FORLING. It was composed of a piston-cylinder assembly attached to a double silicon protector and to a head that connected it to the cylinder. The oral protector was inserted

and fitted in the mouth of the patient, who was required to push the cylinder head with the tongue with the maximum force he could exert for 10 seconds. This procedure was repeated three times, with 1-minute intervals between them. The cylinder head hydraulically transmitted the produced force to a pressure sensor. The pressure sensor measurements were transmitted through a data acquisition device to a personal computer. The method was tested with four healthy subjects, two women and two men aged from 23 to 32 years. The obtained results for the maximum force were 25.7 N, 21.7 N, 21.6 N and 21.1 N, while those for the average force were 20.6 N, 18.2 N, 17.4 N and 18.6 N (Motta et al. 2004).

Another group measured tongue protrusion force using a force transducer (Grass FT10 Force Displacement Transducer) trapped in a vertical surface. The instrument had a piece that was to be placed in the oral cavity. This piece had a cushion for teeth positioning, which the subjects had to bite and press the tongue against a round 20-mm diameter button connected to the force transducer by a cylindrical steel beam of 5 mm diameter and 50 mm length. The button protruded 25 mm from the cushion inside the oral cavity. The maximum protrusion force in voluntary contraction was measured for 5 seconds and the percentage of the force related to maximum force was shown in an oscilloscope to provide visual feedback. The measurements were performed in 12 male subjects with an average age of 23 years, and the maximum obtained force was 24.3 ± 6.7 N (O'Connor et al. 2007).

The palatal plate developed by Kieser et al. (2008) was designed to simultaneously measure pressure at diverse locations in the mouth and was constructed from a chrome-cobalt alloy. To measure pressure during swallowing, an anterior pair of gauges measured lingual and labial contact against the left central incisor tooth, while two pairs of gauges measured pressure contributions of the lateral tongue margin and cheeks on the canine and first molar teeth. Finally, lingual pressure on the midline of the palate was measured by two gauges, one at the position of the premolars and one on the posterior boundary of the hard palate. The 8-channel output was gathered simultaneously and then recorded and displayed on a computer. They recorded intraoral pressures in five adult volunteers during swallowing of 10 mL of water. The pressure ranged from 13.05 kPa to 289.75 kPa.

Utanohara et al. (2008) used a tongue pressure measurement device consisting of a disposable oral probe, an infusion tube as a connector and a recording device. The probe was assembled with a small, partially inflated bulb made from medical grade latex, a plastic pipe as a connector and a syringe cylinder for the patient to hold on. A recording device with a manual autopressurization system was used. By pushing the pressurization button, the probe was inflated with air at an initial pressure of 19.6 kPa. This pressure was taken as the standard and measurements were performed after zero calibration. The subjects were asked to place the bulb in their mouth, holding the plastic pipe at the midpoint of their central incisors with closed lips, to raise the tongue and compress the bulb onto the palate with maximum voluntary effort, and the maximum value was recorded. Tongue pressure was measured in 843 subjects between 20 and 79 years old. The average maximum tongue pressure was 41.7 ± 9.7 kPa in subjects between 20 and 29; 41.9 ± 9.9 kPa (30 to 39 years old); 40.4 ± 9.8 kPa (40 to 49 years old); 40.7 ± 9.8 kPa (50 to 59 years old); 37.6 ± 8.8 kPa (60 to 69 years old) and 31.9 ± 8.9 kPa (70 to 79 years old).

Another study made with FORLING (Barroso et al. 2009) quantified tongue force of 10 subject aged between 14 and 80 years whose tongues were classified as normal or as having a small deficit in force and found average force values between 3.55 N and 13.24 N and maximum force values between 4.97 N and 19.96 N.

A study used the Iowa Oral Performance Instrument (IOPI) to measure tongue pressure of 39 young adults (17 men and 22 women). IOPI is a commercially available tongue pressure measurement system composed of an air-filled bulb connected to a pressure transducer. The bulb was placed in three different positions in the oral cavity, so that they could measure tongue protrusion, lateralization and elevation. In the last two positions, a blade was used to hold the bulb. Three measurements were made for each subject and the higher value was considered the maximum pressure. The average maximum tongue pressures found for all subjects were around 55 kPa for lateralization, 62 kPa for elevation and 65 kPa for protrusion (Clark et al. 2009).

The Myometer 160 used by Lambrechts et al. (2010) contained a probe consisting of two plates that were screwed together on one side. On the other side (probe tip), the two plates could be pushed towards each other. The applied force was measured by an electronic device installed between the plates and shown on a bar graph. To measure tongue force, the patient placed the lips around the opening of the plate and protruded the tongue as hard as possible against the probe tip. Tongue pressure of 107 subjects (63 females and 44 males) between 7 and 45 years old were measured. The average tongue pressure was 1.66 N.

## 2.3 Instrument proposed to measure tongue force

The prototype of the device developed by the Group of Biomechanics of UFMG  for measuring the force of the tongue, Portable FORLING, has the following characteristics: good fixation and stability in the patient's mouth; portability; lightweight; low cost; simple operation; reliable indication of tongue force protrusion; a wide range of force; good repeatability; small size; immune to external influences (temperature or voltage fluctuation); comfortable for the patient; made of biocompatible material; resistant to crashes and easy to sanitize.

Portable FORLING is shown in Figure 3. It consists of two parts, one that goes in the mouth of the patient (where the sensor is located) and another for the data acquisition system.



Fig. 3. Portable device for measuring the force of the tongue: Portable FORLING.

The mouthguard consists of a commercially available double mouth protector used by boxers, with an anatomical shape composed of a biocompatible, nontoxic, lightweight and flexible material so as not to cause discomfort, and allows reuse. It is made of moldable material, acquiring the shape of dental arches, which makes it adaptable to patients with malocclusion.

The function of the mouthguard is to keep the device stable in the patient's mouth, so that the position of the force applicator plate is always the same for a given patient. It is also important to guarantee that the relative motion of the patient's body does not interfere with the force measurement. The dimensions of the mouthguard coincide with the teeth, length of dental arches and relationships between the positions of the tooth centers, as described in the literature (Wheeler and Major 1987; Silva and Pecora 1998; Proffit et al. 2007). The mouthguard has a cutout to accommodate the upper and lower lip frenulum and an opening in its front to accommodate the base piece.

There is a set of small pieces at the inner surface of the mouthguard, which consists of a base, a force sensor, an applicator pin, a holder and a force applicator. This set is positioned this way to absorb the force of protrusion of the tongue. All components of the prototype are biocompatible. The mouthguard and its internal parts are shown in Figure 4. The sensor is positioned between the base and pin applicator.
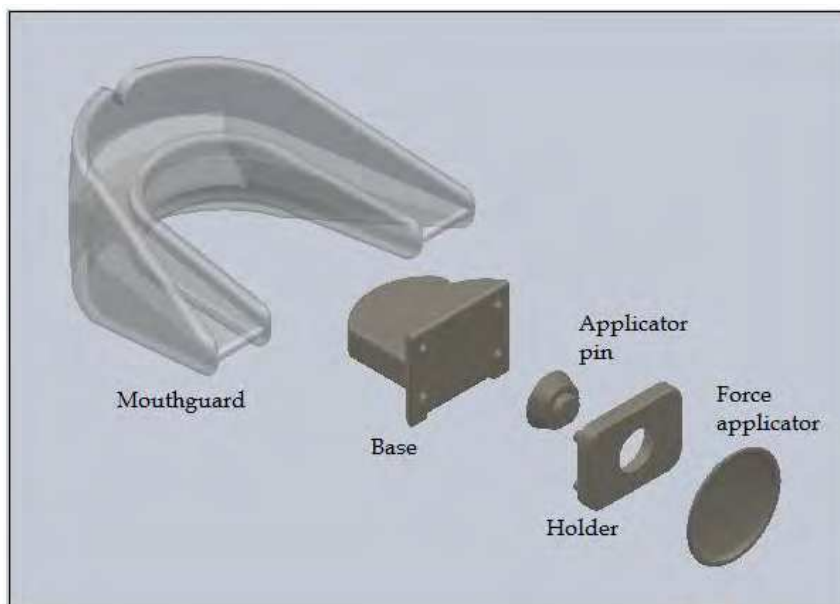


Fig. 4. Illustration of the mouthguard and its internal parts.

The inner parts of the mouthguard were made by stereolithography in epoxy, providing the required mechanical characteristics of stiffness and strength.

The prototype was designed to use small size, thinness, lightness, flexibility and low-cost force sensors, the FlexiForce type A201. A picture of the sensor used is shown in Figure 5.
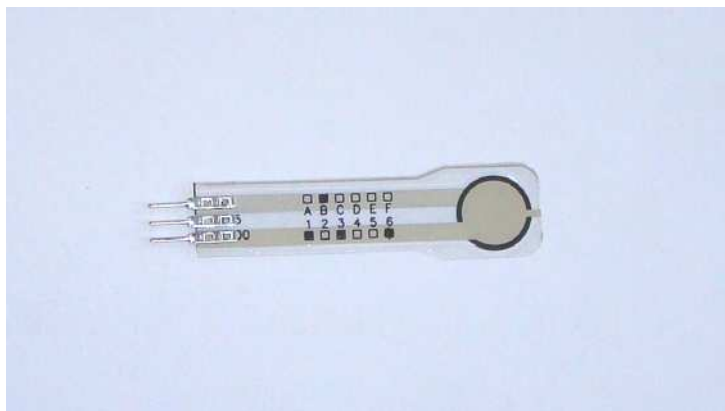
Fig. 5. FlexiForce Sensor  (Tekscan) Model A201.

FlexiForce sensors use technology based on resistivity. The application of a force in a sensitive area elicits a change in resistance of a sensing element inversely proportional to the applied force.

The sensors are encapsulated and their movements are restricted to prevent errors in the generated force signal. In addition, there is an adequate guide to the force applicator.

To ensure accurate and repeatable readings of force, care has to be taken to assure that the applied load is evenly distributed in the sensitive area of the sensor and is not supported by the external area.

The signal conditioning is made using operational amplifiers for signal linearization and conversion of electrical resistance into electrical voltage. The signal goes through an amplification system to ensure the adequate quality of the result, since the data acquisition system is at a considerable distance from the measuring point.

The data acquisition system is composed of three main modules:

- Antialiasing filter;
- Analog to digital converter;
- Serial communication.

The sampling rate is 10 Hz, ensuring compatibility with the characteristics of USB communication and is sufficient to obtain the desired information about tongue force.

Communication with the personal computer is controlled by software as well as the timing between the data and the computer, which is used as a monitoring system, storage system control and data acquisition.

The software was developed by one of the researchers at the Universidade Federal São João Del Rei, using a Matlab platform that allows the evaluator to conduct the evaluation process and store all relevant information.

At the end of three measurements, a report is generated that presents the force profile of the patient. This report records the graphics of force over time (profile) of the three

measurements taken, as well as the values of maximum and average forces of each measurement, the overall mean and standard deviation of these parameters.

## 3. Lips

### 3.1 Anatomy and physiology of the lips

The orbicularis oris muscle (Figure 6) is the facial muscle responsible for the lips shape and function. Its motor innervation is provided by the facial nerve and its sensitivity by the trigeminal nerve (Cosenza 2005). The orbicularis oris is elliptical, and consists of upper and lower fibers, which form the upper and lower lips that interact in the region of the labial commissure (Figun and Garino 2003). Each of those parts consists of pars peripheralis and pars marginalis segments. The pars marginalis fibers have narrow diameters and are localized in the vermilion area of the lip. When this pars contracts, it presses the lip to the maxillary teeth or inverts it, making the lip cover the incisal and occlusal borders of the teeth. The pars peripheralis consists of horizontal, oblique and longitudinal fibers and surrounds the pars previously described. Contraction of this pars results in labial elevation, an action involved in both facial expression and speech (Rogers et al. 2009).
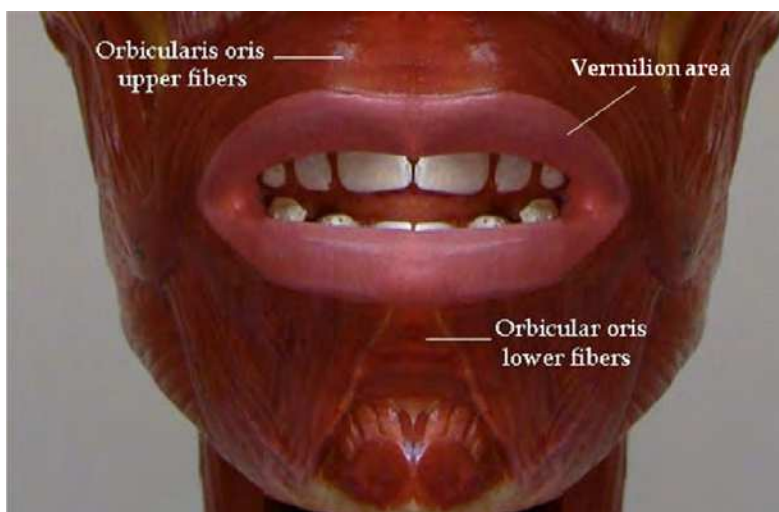


Fig. 6. Orbucularis oris muscle and vermilion area

Lips contraction is essential for many oral functions as it produces closure of the mouth and is necessary in speech, food prehension and swallowing. Lips also participate in the actions of blowing, sucking, kissing and whistling (Figun and Garino 2003). In suction and swallowing, the sealing of the lips is necessary to promote intraoral pressure; in speech, lips work by interrupting the air flow, favoring the pronunciation of different phonemes such as /f/, /v/, /b/, /p/ and /m/ (Douglas 2002), or modifying the shape of the oral cavity, changing voice resonance and helping to produce the vowels.

Since the inferior lip position depends on mandibular movements, this is the more mobile of the two and also the faster. Most of the facial expression muscles are inserted into the lips, which contribute to the great variability of labial movements (Zemlin 1997).

Another important function of the lips is to exert pressure on the teeth in the superior and inferior dental arch. The lips balance the force made by the tongue on teeth. Tongue muscles push the teeth outwards while the lips, when closed, provide resistance to that force, as their contraction presses teeth intraorally. This force balance allows dental elements to erupt and remain in the correct position in the oral cavity (Proffit and Fields 2002). The orbicularis oris together with other muscles act like a muscle strip, orienting growth of the jaws. When the lips are not sealed, there is no action of this muscle strip, possibly leading to some dysfunctions in jaw growth and teeth eruption (Gonzalez and Lopes 2000).

Dysfunctions in lip muscles can initiate important functional problems, one of which is speech distortion characterized chiefly by imprecision of the sounds that require orbicularis oris contraction (Farias et al. 1996). Another one is a dysfunction in feeding functions, like mastication and swallowing, in which the non-closure of the lips leads to difficulties in maintaining food in the oral cavity and generating negative intraoral pressure, which is indispensable for correct food propulsion (Biazevic et al. 2010).

### 3.2 Instruments described in the literature to measure lips force

The first studies on lips force measurement are from the 1970s. Although the efforts to obtain a numerical value are valid, it is important to observe the agreement with clinical practice diagnosis. Garliner (1971) described the use of a dynamometer, which was adapted into a shirt button attached to a wire. An important question about that study, although it measured values of force, is that traction of the wire was made by the patient, which introduced a subjective element, since the applied force varied from patient to patient and did not allow the establishment of appropriate relationships between individuals.

Posen (1976) reported the development of a device to measure the force of the perioral muscles using a rigid rod and a small circular shaped insert. In this case, the patient was asked to position the lips surrounding this insert and impose traction with the head against the rod as hard as possible. The author evaluated 170 women and 166 men aged between 8 and 18 years with normal occlusion, and categorized the measurements carried out as follows: 160 g to 175 g for individuals with weak lips; 180 g to 195 g for individuals with slightly weak lips; 200 g to 215 g for those with moderate lips force; 220 g to 235 g for those with slightly increased lips force and 240 g to 260 g for individuals classified as having increased lips force. The subjective component was still considerable because head movement was used in addition to the lips.

A study aimed to determine whether advancing age could significantly interfere with the generation of oral forces. Forty women aged between 20 and 100 years were evaluated. For that, leverage force sensors coupled to the incisor teeth were used in both the upper and lower dental arches. The contraction time required for each examination was 5 seconds. Measurements were made during oral functions and maximum voluntary

contraction of the lip muscles. The subjects were separated into subgroups according to their age. The mean values of maximal contraction of the upper lip were about 5.8 N for women aged 20 to 60 years, and 4.0 N for women between 80 to 100 years old. For the lower lip, these values ranged from 11.0 N for the first group and 10.0 N for the second. There were significantly higher strength values for the lower lip compared with the upper lip. However, little differences were observed between the subgroups (McHenry et al. 1999).

In the same way, two groups of researchers (Cantero et al. 2003 and Gonzalez et al. 2004) described a method of assessing lips force based on an instrument constructed using a dynamometer. A stainless steel plate was adapted into the dynamometer and the subjects could bite the plate, having a mouthguard as support that was sterilized after use. No further details were given about the methodology. The authors described three measurements for each subject and the analyzed parameter was the highest value of the three trials. In one of these studies, Cantero et al. (2003) evaluated lips force of 90 children before and after speech-language therapy. The measured force values significantly increased after orofacial myofunctional therapy, ranging from 1.68 N to 1.82 N before treatment and from 2.05 N to 2.34 N after treatment. Using the same methodology, another group (Gonzalez et al. 2004) evaluated 180 children between 5 and 12 years old, 90 with lip seal and another 90 with incompetent lip seal. Two measurements were made in children who had incompetent lip seal, one before and one after treatment. The results indicated force values ranging from 1.57 N to 2.15 N before treatment and 2.03 N to 2.72 N after treatment. Moreover, boys presented higher lips forces.

Another usual goal is the verification of malocclusion. Jung et al. (2003) evaluated 32 male students, who had Angle Class I and obtained an average force varying from 3.3 N to 13.1 N, while the maximum force ranged from 4.3 to 20.3 N. Earlier, Unemori and colleagues (1996) examined two individuals before and after orthognathic surgery and obtained force values ranging from 1.0 to 2.2 gf/mm$^2$.

Hägg and Anniko (2008) recently conducted a retrospective study involving 30 subjects aged between 49 and 88 years who had suffered a stroke. They measured lips force using the Lip Force Meter (LF100). This instrument consists of a transducer that is placed between the lips and teeth and is attached to a steel wire, which is connected to a load cell. After acclimatization, the examiner held the instrument and asked the subjects to contract their lips in order to pull the wire. Lips strength evaluation and swallowing performance analyses were done. The evaluations were conducted pre and post myotheraphic intervention. The average lips force was 7 N before starting treatment and 18.5 N after the intervention and this correlation was statistically significant. An improvement in the ability of swallowing after therapeutic intervention was also observed.

## 3.3 Instrument proposed to measure lips force

The FORLAB lips measurement system (Figure 7) is composed of an intralips insert, against which the patient presses the lips to generate a counter-resistance force. This force is transmitted to the load cell, by mechanical coupling. The load cell generates an analog signal in tension that is treated, transmitted, processed and saved.

Fig. 7. Portable device for measuring the force of the lips: FORLAB.

The insert (Figure 8) has an elliptical shape with parabolic curvature and a lateral dimension of 60 mm. The manufacturing process was rapid prototyping using nontoxic polymers, which follows the biosafety recommendations for use in human beings.
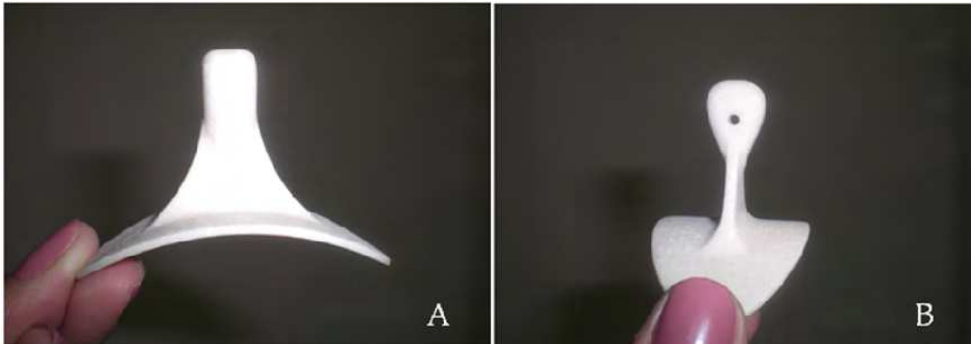


Fig. 8. Frontal (A) and lateral (B) view of the insert.

The insert is positioned as in the qualitative evaluation, leaving a gap between the lips and the dental arch, so that the patient can pull it with the lips (Figure 9), thereby generating a resistance force. This force is transmitted to the load cell by mechanical coupling, in this case, provided by a steel wire. The load cell has a capacity of 50 N, is electronically connected in bridge and generates an analog signal when pulled in traction. A head support is used to prevent the person from generating the force with the head instead of the lips.

Fig. 9. FORLAB in detail.

The transmission, processing and storage system was especially developed for this study. It is composed of a data acquisition board (Ontrak), an electronic coupling system and an IBM-PC personal computer. The measurement system interacts with the evaluator by a human-machine interface that uses high level programming language and is distributable in a Windows® platform. The stored signals are used to characterize the force profile of the subject. Besides the force x time curve (profile), it is possible to evaluate relevant typical points like maximum force, average force and variations that characterize the lips force of the subject.

## 4. Studies made with the proposed devices

The initial studies accomplished using FORLING and FORLAB devices aimed to describe the characteristics of the tongue and lips in healthy subjects without any disturbance to the structures or functions of the oral sensorimotor system.

### 4.1 Methodology

The studies were conducted with approval of the Human Ethics Committee from the Universidade Federal de Minas Gerais. The sample was composed of 20 young women aged between 21 and 33 years with no history of swallowing, respiratory or speech impairments. Moreover, they had no existing medical condition or medication use that could potentially influence orofacial performance or sensation, and no cognitive or intellectual dysfunction.

After providing their informed consent, the subjects first underwent a qualitative evaluation of tongue and lips force. In the qualitative evaluation of tongue force, the subjects had to press the tip of their tongue against the finger of the examiner and against a tongue blade for 10 seconds, with resistance provided by the examiner (Figure 10A). The qualitative evaluation of lips force was done by palpating the musculature at the resting position and in centric isometric contraction, as well as evaluating the strength of resistance against the finger of the examiner placed in the oral vestibule, also for 10 seconds (Figure 10B).
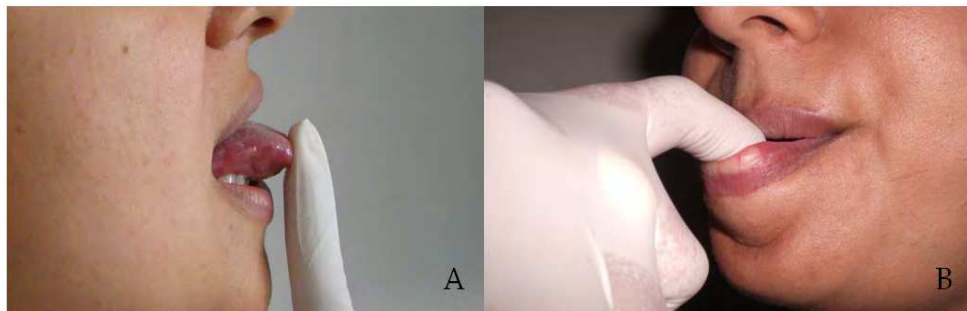
Fig. 10. Qualitative evaluation of tongue (A) and lips (B) force.

After qualitative analysis, the women classified as having normal force according to the judgment of two speech language pathologists were directed to a quantitative assessment of tongue or lips force. These structures were classified as having normal force when they were able to perform protrusion movements against strong resistance exerted by the blade and/or the finger and maintain the force without shaking and deformation.

Ten women were randomly selected to participate in the tongue research using Portable FORLING, and ten women were selected to participate in the lips research using FORLAB.

Measurements were made in a clinical room at the Speech-Language Pathology Ambulatory of the University. Participants were seated comfortably in an upright position and instructed to fit the device into the oral cavity with the help of the examiner. The patients had one minute for acclimatization before undergoing three consecutive trials, in which they performed isometric muscle contractions sustained for 10 seconds, the same period of time for the qualitative assessment. It is important to consider that a very long time of sustained maximal contraction can cause muscle fatigue and thereby compromise the results. One-minute time intervals were given between trials to avoid fatigue.

The interval time for rest and the time for sustained force were controlled by software specially developed for each of the instruments and a beep indicated each of these steps. The sampling rate was 10 Hz.

## 4.2 Results and discussion

The results obtained by the clinical application of FORLING and FORLAB are presented below. The parameters analyzed were average force and maximum force obtained in the determined period of sustained muscle contraction. Information about data dispersion as standard deviation and coefficient of variation were also recorded. The strength profile of both structures was compared, as well as the stability characteristics.

There were notable differences in the curves of the force over the period of sustained contraction. The tongue's profile can be described as presenting an initial peak of force that gradually decreases. On the other hand, the analysis of data concerning lips force showed a profile characterized by little amount of variability over time and without any noticeable peaks. The decay in the lips' profile curve was slower than that of the tongue. The decay in the tongue/lips strength curve can be explained by physical causes such as muscle fatigue or

motivational causes such as mental fatigue and lack of interest. Figure 11 shows typical curves obtained from the quantitative evaluations of the tongue and lips.
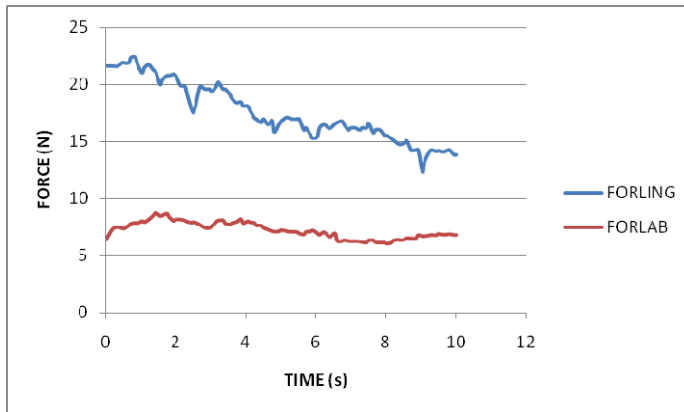


Fig. 11. Profile of the tongue and lips force over time.

The tongue force was higher than that of the lips, in the analysis of both average force and maximum force. Table 1 presents the results of the trials. It was verified that both parameters increased over successive trials, indicating that there is a learning effect.

|  | TONGUE | | | LIPS | | |
|---|---|---|---|---|---|---|
|  | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 |
| Maximum Force (N) | 19.9 | 21.9 | 22.5 | 10.6 | 11.1 | 11.1 |
| Maximum force SD | 5.5 | 6.7 | 5.6 | 2.5 | 2.4 | 2.7 |
| Average Force (N) | 15.8 | 16.9 | 17.0 | 9.3 | 9.0 | 9.3 |
| Average Force SD | 4.9 | 6.1 | 4.6 | 2.6 | 2.5 | 2.4 |

N = Newton; SD= Standard Deviation.

Table 1. Maximum force and average force of tongue and lips.

For the analysis of stability, the coefficient of variation (CV) was used, which is a dimensionless value that provides information about the homogeneity of the results. CV is the result of the division of the standard deviation by the average value, involving data from the same series. The lower the magnitude of CV, the greater is the uniformity of results. A CV lower than 10% was considered low, between 10 and 20 % was considered medium, between 20 and 30% was high and above 30% was thought of as very high.

Tables 2, 3 and 4 present the average force values and the analysis of dispersion of these values for each participant in trials 1, 2 and 3, respectively.

The average tongue force had a high CV compared to lips force, which were classified as low or medium. This can be explained by the characteristics of each of these structures, since the tongue is composed of a set of muscles that contract in a coordinated way, while the lips comprise only one muscle. In an attempt to keep the contraction over ten seconds, the participants exerted peaks of force interspersed with regions of decay in the force measured by Portable FORLING, while FORLAB showed a more stable signal.

| Participant | Structure evaluated | Average force (N) | Standard deviation | Coefficient of variation (%) |
|---|---|---|---|---|
| 1 | Tongue | 12.3 | 2.2 | 17.84 |
| 2 | Tongue | 7.8 | 1.9 | 24.27 |
| 3 | Tongue | 18.0 | 1.6 | 9.00 |
| 4 | Tongue | 11.6 | 2.3 | 19.88 |
| 5 | Tongue | 10.6 | 1.5 | 14.27 |
| 6 | Tongue | 5.8 | 1.8 | 30.24 |
| 7 | Tongue | 11.0 | 1.8 | 16.47 |
| 8 | Tongue | 20.5 | 3.0 | 14.74 |
| 9 | Tongue | 18.7 | 1.4 | 7.26 |
| 10 | Tongue | 13.6 | 2.6 | 18.97 |
| 11 | Lips | 13.2 | 1.0 | 7.68 |
| 12 | Lips | 7.5 | 0.4 | 4.85 |
| 13 | Lips | 7.0 | 0.4 | 5.45 |
| 14 | Lips | 12.5 | 0.9 | 6.95 |
| 15 | Lips | 5.8 | 1.0 | 17.65 |
| 16 | Lips | 10.2 | 0.6 | 5.67 |
| 17 | Lips | 9.1 | 0.5 | 5.99 |
| 18 | Lips | 8.3 | 0.8 | 9.91 |
| 19 | Lips | 7.5 | 0.6 | 7.80 |
| 20 | Lips | 12.2 | 0.3 | 2.47 |

N = Newton.

Table 2. Measurements of central tendency and dispersion of force values obtained in Trial 1.

| Participant | Structure evaluated | Average force (N) | Standard deviation | Coefficient of variation (%) |
|---|---|---|---|---|
| 1 | Tongue | 16.4 | 2.0 | 12.18 |
| 2 | Tongue | 11.8 | 2.0 | 16.79 |
| 3 | Tongue | 19.8 | 2.6 | 13.06 |
| 4 | Tongue | 12.6 | 2.8 | 22.46 |
| 5 | Tongue | 11.2 | 1.5 | 13.58 |
| 6 | Tongue | 7.7 | 2.6 | 33.16 |
| 7 | Tongue | 9.9 | 1.0 | 9.86 |
| 8 | Tongue | 16.4 | 4.2 | 25.32 |
| 9 | Tongue | 18.5 | 1.7 | 9.10 |
| 10 | Tongue | 14.9 | 2.4 | 16.39 |
| 11 | Lips | 14.4 | 1.5 | 10.67 |
| 12 | Lips | 7.2 | 0.7 | 9.75 |
| 13 | Lips | 7.7 | 0.5 | 6.47 |
| 14 | Lips | 10.6 | 1.1 | 10.09 |
| 15 | Lips | 8.7 | 0.9 | 10.55 |
| 16 | Lips | 10.9 | 0.7 | 6.36 |
| 17 | Lips | 8.2 | 0.8 | 9.38 |
| 18 | Lips | 10.2 | 1.4 | 13.53 |
| 19 | Lips | 8.2 | 0.5 | 5.76 |
| 20 | Lips | 11.0 | 0.4 | 4.16 |

N = Newton.

Table 3. Measurements of central tendency and dispersion of force values obtained in Trial 2.

| Participant | Structure evaluated | Average force (N) | Standard deviation | Coefficient of variation (%) |
|---|---|---|---|---|
| 1 | Tongue | 14.8 | 2.6 | 17.68 |
| 2 | Tongue | 14.2 | 2.5 | 17.49 |
| 3 | Tongue | 18.5 | 1.6 | 8.58 |
| 4 | Tongue | 12.8 | 3.5 | 27.00 |
| 5 | Tongue | 11 | 1.7 | 15.06 |
| 6 | Tongue | 9.6 | 2.4 | 24.90 |
| 7 | Tongue | 12.6 | 1.7 | 13.42 |
| 8 | Tongue | 18.4 | 3.7 | 19.91 |
| 9 | Tongue | 18.1 | 2.3 | 12.49 |
| 10 | Tongue | 13.4 | 3.1 | 22.95 |
| 11 | Lips | 14.7 | 1.3 | 9.24 |
| 12 | Lips | 9.0 | 0.4 | 4.74 |
| 13 | Lips | 7.3 | 0.5 | 6.30 |
| 14 | Lips | 11.7 | 2.2 | 18.51 |
| 15 | Lips | 7.1 | 0.4 | 5.17 |
| 16 | Lips | 9.8 | 1.8 | 17.99 |
| 17 | Lips | 9.5 | 1.4 | 14.45 |
| 18 | Lips | 7.4 | 1.0 | 13.56 |
| 19 | Lips | 7.5 | 0.6 | 8.17 |
| 20 | Lips | 8.8 | 0.5 | 5.57 |

N = Newton.

Table 4. Measurements of central tendency and dispersion of force values obtained in Trial 3.

The variability of the signals is due to the complexity of the biological systems. According to Gill (1987) as cited in Judice et al. (1999), a lot of biological characteristics have a CV between 5 and 50%. The wide variation in the amplitude of lingual force values has also been reported by others (Frohlich et al. 1990; Robinovitch et al. 1991). Robinovitch et al. (1991) also attributed tongue slippage and neural-based fluctuations in causing this variation.

By analyzing the values of maximum force (Table 5), it is noteworthy that 90% of the participants showed higher values in Tests 2 and 3. Therefore, the learning factor can be a reasonable explanation for these results.

Many instruments have been developed to quantify tongue force using different technologies, such as dynamometers (Posen 1972; Trawitzki et al. 2010), bulbs (Bu Sha et al. 2000; Hayashi et al. 2002; Clark et al. 2003; Ball et al. 2006; Utanohara et al. 2008), palatal plates (Hori et al. 2006; Hewitt et al. 2008; Kieser et al. 2008), strain gauges (Kydd 1956; Sanders 1968; Dworkin 1980; Robinovitch et al. 1991; Scardella et al. 1993) and others. Each one has its advantages and disadvantages and can measure maximum tongue force in a different direction and sometimes force during function.

Portable FORLING measures tongue protrusion force. It is believed that from the measurement of the ability of the individual to exert a horizontal force towards the outside of the oral cavity (protrusion force), it is eventually possible to infer about the capacity of the tongue to perform other tasks (Motta et al. 2004). This is because the muscles involved in tongue protrusion, the genioglossus and intrinsic tongue muscles, also act during functions of mastication, swallowing and speech among others. Furthermore, the ability to exert

protrusion force can indicate the ability to exert forces in other directions, as shown by some authors (Dworkin and Aronson 1986). In their study about tongue force in the anterior and lateral directions, the results indicated that subjects presenting higher force values in one direction also did so in the other directions, and the same happened to those who showed lower forces. However, the main reason for choosing protrusion force was that it is the force direction usually evaluated by speech pathologists in clinical assessment. Thus, it is possible to establish comparisons between the qualitative and quantitative evaluations. Similarly, the quantitative evaluation of lips has the same principle as that of the qualitative assessment.

| Participant | Structure evaluated | F max T1 (N) | F max T2 (N) | F max T3 (N) |
|---|---|---|---|---|
| 1 | Tongue | 16.1 | 19.8 | 19.7 |
| 2 | Tongue | 11.4 | 15.0 | 18.1 |
| 3 | Tongue | 20.7 | 23.8 | 21.9 |
| 4 | Tongue | 15.0 | 17.5 | 18.8 |
| 5 | Tongue | 13.7 | 15.0 | 14.2 |
| 6 | Tongue | 11.1 | 12.3 | 13.2 |
| 7 | Tongue | 14.2 | 12.3 | 16.0 |
| 8 | Tongue | 26.1 | 23.3 | 25.6 |
| 9 | Tongue | 22.4 | 23.1 | 23.6 |
| 10 | Tongue | 17.2 | 19.3 | 19.1 |
| 11 | Lips | 14.5 | 16.1 | 16.0 |
| 12 | Lips | 8.1 | 8.7 | 9.7 |
| 13 | Lips | 8.1 | 9.1 | 8.4 |
| 14 | Lips | 14.0 | 13.0 | 14.2 |
| 15 | Lips | 8.0 | 10.2 | 7.9 |
| 16 | Lips | 11.6 | 12.2 | 11.3 |
| 17 | Lips | 9.9 | 10.1 | 12.1 |
| 18 | Lips | 9.9 | 13.2 | 9.4 |
| 19 | Lips | 8.7 | 9.2 | 9.0 |
| 20 | Lips | 12.8 | 12.3 | 12.3 |

F max= Maximum force; N= Newton ; T1= Trial 1; T2= Trial 2; T3= Trial 3.

Table 5. Maximum force in each trial.

Data obtained in this research was compared to other studies that used the same assessment direction in maximum voluntary contraction (Kydd 1956; Posen 1972; Dworkin et al. 1980, Mortimore et al. 1999; Motta et al. 2004; Barroso et al. 2009; Lambrechts et al. 2010). The values obtained in this research were similar to the ones achieved by Kydd (1956) (maximum force: 23.13 N), Posen (1972) (maximum force between 6 N and 25 N), Dworkin et al. (1980) (maximum force was 32.9 N for men and 27.5 N for women), Mortimore et al. (1999) (maximum force: 26± 8N for males and 20± 7N for females), and Motta et al. (2004) (maximum force between 21.1 N and 25.7 N and average force between 17.4 N and 20.6 N), and higher than those obtained by Barroso et al. (2009) (average force between 3.55 N and 13.24 N) and by Lambrechts et al. (2010) (average force 1.66± 0.06 N). However, in the study by Barroso et al. (2009), the sample was composed of subjects with tongue strength classified as normal or slightly reduced in the qualitative assessment, which probably resulted in lower tongue force values, combined with the fact that the age range of the sample included

individuals older than 60 years. According to Crow and Ship (1996), a reduction in muscle mass happens after 60 years of age due to atrophy and loss of motor neurons. Lambrechts et al. (2010) included children, who had lower tongue strength than adults due to their stage of developmental maturation in muscle morphology and the central nervous system (Potter et al. 2009; Potter and Short 2009). Moreover, the authors did not provide information about the qualitative evaluation of their participants.

It can be argued that several problems are encountered in the process of measuring the strength of the oral structures, such as lips and tongue. This is because they are structures within the complex biological orafacial system, susceptible to environmental, behavioral and anatomical changes. Therefore, as stressed by Ingervall and Janson (1981), assessing the strength of the lips in a quantitative way is not an easy task. There are different methodological approaches for assessing labial force as presented in the literature. Most of these studies have generated a solution by adapting dynamometers (Garliner 1971; Posen 1976; Ingervall and Janson 1981; Thuer and Ingerval 1990; Cantero et al. 2003; Gonzalez et al. 2004). The disadvantage of this line of instrumentation is the need for a person to conduct stabilization or move the traction device pulling the lips, in order to measure the strength of this structure. This introduces subjective components into the process, since each professional will act slightly differently when supporting the instrument. Moreover, the possibility of evaluating different directions of lip contractions makes comparison between the findings of different studies unreliable. Some researchers have sought to evaluate the lip closing force from the closing of a plate positioned horizontally between the upper and lower lips (Jung et al. 2010). When using this instrument, great attention should be given to controlling the action of compensatory muscles, such as the mentalis. Other assessing instruments reported in the literature use force or pressure lip sensors attached to the teeth (Gentil and Tournier 1998; McHenry et al. 1999; Ruan et al. 2007). These electrodes are fixed by special glues or dental adhesive. The disadvantage of these instruments is the difficulty in accommodating the idealized electrodes at points and in the positioning of the electrodes for comparative reassessments. The ultimate goal of researchers using sensors supported on the teeth is to assess the action of these muscles on the correct teeth positioning as well as studying the balance of power between the lips and tongue. A study in the literature (Hägg and Anniko 2008) evaluated the lip force of contraction in the same way as that proposed by the FORLAB report, but with a population of patients who had suffered a stroke. Considering the results obtained by the authors after the process of force lip rehabilitation, higher average values (18.5 N) were observed when compared to those obtained in the measurements performed with FORLAB. It is important to consider that a muscle group exposed to specific training will gain strength in a manner that can also generate greater force against resistance. It is believed that even subjects without functional complaints and with adequate lip strength during qualitative assessment, like the subjects evaluated with FORLAB, can increase their capacity of generating force after being submitted to muscular training.

It is known that clinical evaluation, which is considered subjective as it does not quantify the force values and depends on the clinical experience of the evaluator, is the reference assessment for professionals in this area. The proposal is to develop instruments that can help this assessment by offering quantitative data. The presented systems follow the same principles as those of clinical evaluation, analyzing the same type of force (counter-

resistance). This makes comparisons between the two assessments (qualitative and quantitative) possible and consistent. All the subjects analyzed in this study presented normal tongue strength. Future studies are being planned to compare alterations in clinical assessment (diminished or enhanced force) with numerical values.

Considering the clinical application of FORLAB, some difficulties were found, such as the standardization of the distance between the insert and the frontal teeth, and the correct positioning of the steel wire (mechanic coupling). The distance to the position of the insert was measured subjectively from the region the insert touched the teeth. The traction made by the evaluator caused a displacement of 10 mm, generating a slight projection of the lips. To allow correct mechanical coupling, the wire positioning was also made subjectively. The evaluator adjusted the system parts so that the wire would be as strained as possible. These problems can be solved by substituting the steel wire for a rigid mechanical coupling, like a metal rod, and the marking of a point that allows the visualization of the distance between the teeth and the insert. A new version of this instrument is in development to resolve these problems.

In both instruments, intra-subject analysis presented more significant results, since evaluating biological systems involves the consideration of many particularities and peculiarities. Thus, the quantitative analysis of tongue and lips force can be an efficient instrument in comparing the changes in a patient during therapy.

## 5. Future direction

More research is needed in the Biomechanics area, especially related to orofacial structures. The Biomechanics Engineering Group is already developing a new version of FORLAB, which will be portable like Portable FORLING, and will eliminate most of the restrictions associated to the first version. The portable FORLAB will also be able to detect differences in force generated by each side of the orbicular oris muscle which is especially important in the evaluation of patients with facial palsy.

Next studies in tongue and lips force will explore other parameters beyond maximum and average force: the average force application rate, which is the speed that the force reaches the higher peak, and the area under the graphic, which is related to the energy dissipated during the task. These parameters are also important to characterize tongue and lips force profile and they need to be investigated in a high number of individuals with different classifications of force, in order to create standard values for each of these groups.

Cheeks form the lateral boundary of the buccal cavity, and display continuity with the lips. They participate, together with the tongue, in the acts of suction, swallowing and mastication. A device to measure cheeks force is also being developed in collaboration with UFRGS (Universidade Federal do Rio Grande do Sul), a university in the Brazilian city of Porto Alegre. It is being based in the same principles of trying to represent the current evaluation technique, proving reliable results and a safe and portable basis. Other devices under development involve gadgets to train and rehabilitate tongue, cheek and lip forces.

These developments show an important potential, as they intend to allow pathologists to be sure of how much load the patient is training with, and to make possible to alter the clinical procedure when required, fixing the ideal force value to be used in training as well as the

duration and the number of exercise series. It will also be possible to make biofeedback therapy.

## 6. Conclusion

To effectively rehabilitate orofacial muscles it is important to consider their characteristics. They have precise and complex movements that are specific to function they are responsible for. The tongue for example is constituted not only of one muscle, but of a set of small muscles which are organized in different directions and work in synchrony promoting a wide range of refined movements. The amount of movements can be justified by the complexity of the functions directly related to the tongue, like speech, mastication and swallowing. On the other hand, the lips muscle has quite different characteristics. It has reduced caliber and its movements are not as elaborated as the ones of the tongue. Knowing these features will enable the rehabilitation process to be directed to each muscle group affected.

Tongue and lips are very important in orofacial functions. To be able to perform the functions properly, they need to be able to generate appropriate force. Thus, it is very important to measure tongue and lips force, especially in patients that have orofacial dysfunctions. This chapter presented the development and application of two instruments developed by the Biomechanics Engineering Group that measure forces of orofacial structures. The Portable FORLING measures tongue force and is composed of a mouthpiece, a base, a resistive sensor, pin and force applicator and a holder, all connected to a data acquisition and processing system. FORLAB measures lips force and is composed of an intralips insert, a stainless steel wire, a load cell and data acquisition and processing system. They were used in studies with normal subjects and proved to be effective and helpful for speech pathologists to improve their assessment. In subjects with normal tongue and lips strength in clinical evaluation, average tongue force was 16.6 N, with average CV of 17.3% and average lips force was 9.2 N with average CV of 7.4%. The tongue presents a force profile over time that is characterized by a force peak followed by the decay of force values, while lips demonstrate stability while maintaining maximum contraction over time. Those results indicate that forces of the lips are lower, but more stable than the ones of the tongue. The described developments were possible due to the multidisciplinary character of the group, including an active exchange between professionals of different background and institutions with the common goal of providing useful and reliable solutions for relevant problems in orofacial myology.

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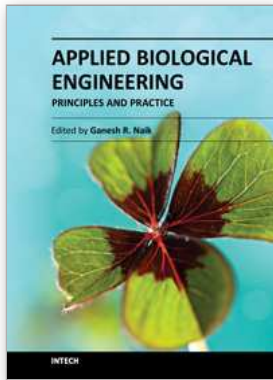
**Applied Biological Engineering - Principles and Practice**
Edited by Dr. Ganesh R. Naik

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